STM Corporation

Subcontractor:	STM Corporation 275 Metty Drive Ann Arbor, MI 48103
Contracting Party:	Sandia National Laboratories
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Introduction

Pursuant to SNL’s contract #BC-0002A, STM Corporation has been developing an SMB system based on STM’s 25-kW Stirling-cycle engine: the STM4-120 [(1)]. The Stirling-cycle engine is externally heated and thus requires merely a sufficiently hot flow of combustion gases through its heat exchanger to produce power. A Stirling-based biopower system can then be implemented simply by directing the gaseous products of the combustion of solid biomass fuel through the heat exchanger of the engine, in contrast with ICE-based systems that require the solid biomass fuel to first be converted into cool and clean gaseous fuel.

The objectives of Phase 1 have been to develop technical and business strategies for incorporating the STM 4-120 engine with a solid biomass combustion system, into an SMB system and to commercially introduce this system into suitable markets. The approach to the Phase 1 study was based on the recognition that commercial introduction will be strongly facilitated by employing a developed engine that will be mass-produced for a number of applications.

STM engaged the Antares Group to conduct a market assessment study and a biomass resource assessment study. Inputs from these studies were used to design a complete biopower system made up of the STM 4-120 Stirling engine close-coupled to a commercial updraft sawdust gasifier and equipped with an induction generator to produce grid-connected electric power. The design was then used to assess the performance, costs, safety, and environmental impacts of the system. Finally, all this information was taken into consideration in developing a preliminary business plan and commercialization strategy.

Potential Markets

The domestic market potential was based on the estimated amount of sawdust available. Previous analyses showed that sawdust presents the most viable biomass feedstock for the BioStirling system because of its abundance and physical characteristics. Sawdust is generated by both primary and secondary wood processing facilities. Residue that is disposed of at no higher value to the mill was considered to be “available” for use as feedstock. This category includes residue that the mill gives away, pays to have removed, stockpiles onsite, incinerates onsite, landfills, or scraps in any other way. The market is the number of STM units that can be supported annually multiplied by available sawdust. The total revenue was arrived at by assuming STM captured 100% of this market. The price per 25-kW unit was assumed to be $40,000, and each unit needs to be fueled by 457 tons of sawdust per year. For the primary mills market, the analysis shows that STM has the potential to sell 4040 units and collect $161 million in revenue. For the secondary mills market, STM has the potential to sell 1258 units and collect $50 million in revenue, across the United States.

Table 12 outlines some key assumptions:

Table 12. Summary of Domestic Market Potential Assumptions

Variable	Value
System Size	25 kWe
System Cost	$1,600/kW
System Efficiency (electrical)	29,246 Btu/kWh
Operating Hours	7000 h/yr
Fuel HHV (@ 30% MC)	5600
Sawdust Required/Unit	457 tons/yr
Secondary Mill Residues/ Primary Mill Residues	0.31 ton/ton
Avail. Sawdust/Total Avail. Residues	0.39 ton/ton

A first approximation was made of the international market potential for each country analyzed in this report. Results showed that if it captures 100% of the market, STM has the potential to sell 9371 units and collect $375 million in revenue across the 21 countries in this analysis.

The economic benefit of the BioStirling system to the end user will be the key to its success. This will rely on demonstrating the value of producing on-site electricity/heat and the waste disposal avoidance benefits of this system. A simple tool was developed that provides some perspective on the market conditions that must exist to make the BioStirling system attractive. Table 13 summarizes the analysis in a cross-tabulated matrix. The analysis relies on the following assumptions:

Table 13. STM SYSTEM BENEFITS (cents/kWh)
Accrued through Avoided Residue Disposal Costs and Heating Fuel Offsets

Fuel ($/MMBtu) \ Disposal Costs* ($/ton)	-	2.00	5.00	10.00	15.00	20.00	25.00	30.00	40.00
-	-	0.52	1.31	2.61	3.92	5.22	6.53	7.83	10.44
2.00	4.13	4.66	5.44	6.74	8.05	9.36	10.66	11.97	14.58
2.25	4.65	5.17	5.96	7.26	8.57	9.87	11.18	12.48	15.09
2.50	5.17	5.69	6.47	7.78	9.08	10.39	11.69	13.00	15.61
2.75	4.65	5.17	5.96	7.26	8.57	9.87	11.18	12.48	15.09
3.00	5.17	5.69	6.47	7.78	9.08	10.39	11.69	13.00	15.61
3.50	5.68	6.21	6.99	8.29	9.60	10.91	12.21	13.52	16.13
4.00	6.20	6.72	7.51	8.81	10.12	11.42	12.73	14.03	16.64
4.50	7.23	7.76	8.54	9.84	11.15	12.46	13.76	15.07	17.68

Table results expressed in cents/kWh

**includes tipping fees and other removal costs*

- Overall thermal efficiency of the BioStirling system is 82%.
- Heating fuel is displaced at $2.00-$4.50/MMBtu via heat recovery.
- Tipping fees paid for waste wood removal range from $0.00 to $40.00/ton.

Under these assumptions, the value of offsetting tipping fees and heating fuel costs can exceed 17¢/kWh. The effect of this is illustrated in the following example.

A facility is currently paying $5/ton disposal costs for waste wood. The facility will also be able to use the waste heat from the BioStirling system and currently pays $3.00/MMBtu for heating fuel. Therefore, the avoided cost benefit of the STM system is 6.5 ¢/kWh. The significance of this benefit is illustrated as follows:

Sawmill's current electricity costs as purchased from the grid	5.5 ¢/kWh
Less BioStirling electricity generation (capital plus O&M, fuel is free)	- 4.8 ¢/kWh
Savings in electricity cost	+ 0.7 ¢/kWh
Benefit of avoiding heat and disposal costs	6.5 ¢/kWh
Net benefit realized through BioStirling utilization	7.2 ¢/kWh
Annual Generation	175,200 kWh
Net Annual Benefit (rounded)	**$12,600**

The net annual benefit appears attractive and translates into a 3-year simple payback on the investment. This analysis also suggests that the benefits of avoiding disposal and heating fuel costs will far outweigh the benefits of on-site electrical generation unless the facility is paying very high electricity costs.

Two other considerations enhance the market projection but are not included in the reference case:

- Some states grant a $5/ton credit for the conversion of sawdust into an "economically valuable product," which can include electricity. This credit would add to the overall economic benefit of an end user.

- The system described herein presumes sawdust as the feedstock of choice. Not included in the market projections is that the BioStirling system may also employ, without change, other compatible feedstocks—primarily agricultural wastes.

System Design

Figure 6 shows a schematic of the biopower system. The biomass feedstock is combusted in two stages: The first is a sub-stoichiometric, sub-atmospheric gasification using Chiptec Wood Energy Systems' C-1 updraft sawdust gasifier. The second stage—complete combustion of the gas from the first stage—takes place in a continuous combustor equipped with a jet pump flow inducer. A combustion blower supplies the secondary air to the combustor. The secondary air creates suction at the jet pump throat to induce atmospheric airflow into the gasifier and producer gas flow out through the ash separator and to the secondary combustor where it burns with the secondary air. The combustion gases then flow through the engine heat exchanger, give up its heat to the engine and are exhausted or delivered to an application-specific consumer heat load. Between the gasifier and the secondary combustor are disposed a cyclone fly-ash separator and a bypass system that is activated only upon startup and shutdown of the system. The engine drives an induction generator to produce grid-connected electric power.

The technical specifications of the system are summarized in Table 14.

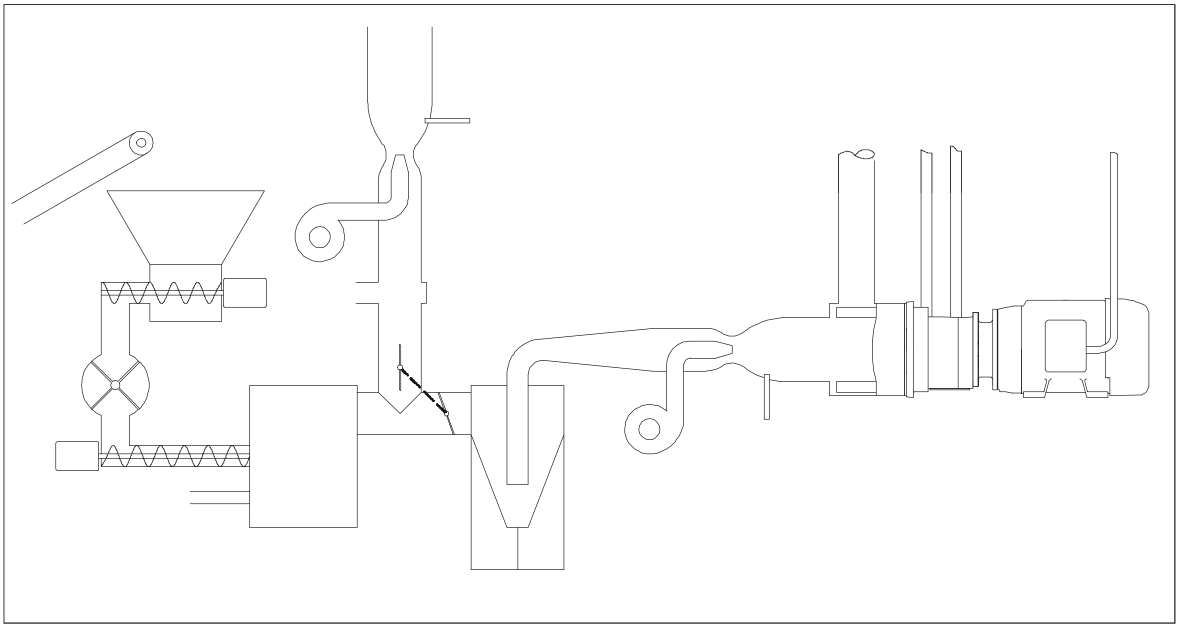

Figure 6. BioStirling System Schematic

Table 14. BioStirling System Specifications

Primary feedstock	Sawdust
Feedstock consumption	59 kg/h
Air flow Primary	24 g/s
Secondary	108 g/s
Total	132 g/s
Electric power	25 kWe
Heat to consumer	140 kWth at 813°C
Coolant heat	41 kWth at 60°C
Energy utilization efficiency	86.5%
Exhaust heat	29 kWth at 200°C
Installation size (L×W×H)	5.66 × 2.87 × 3.66 m
Emission indexes (g/kg) CO	1.0
NO_x	2.5
Design life	50,000 h

A layout of the system is shown in Figure 7.

The BioStirling design concept addresses the following technical issues:

- Fouling and corrosion
- Safety and environmental pollution
- Durability and economical operation.

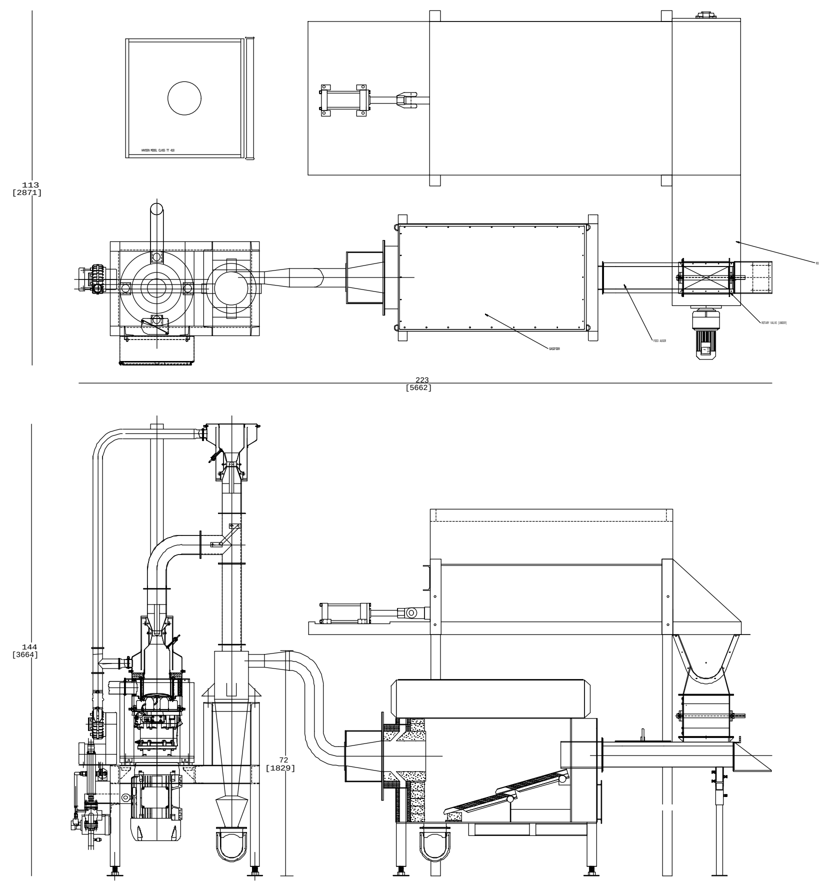

Figure 7. **BioStirling System Layout**

The primary design decisions reflected in the system design are:

- Separating the combustion into a first gasification stage, at about 700°C – below the limit where alkali vapors form and ash fuses, and a second, close-coupled, lean combustion stage so tars in the gas from the first stage never condense. This eliminates the need for scrubbing the gas and the associated problem of having to dispose of liquid effluent. A metallic cyclone fly-ash separator is deployed in the 700°C stream between the two stages. The only disposable waste generated by the system is a small amount of dry ash.

- The air delivery system where the secondary air supply is used to induce the primary air and gas flow maintains the gasifier and gas handling system at sub-atmospheric pressure and greatly enhances the safety of the system. At the same time, the air blower only handles cold air, which reduces cost and enhances the durability and performance of the system.

- Neither the primary nor the secondary air is preheated. This reduces the cost, maintenance requirement, and parasitic losses but requires about twice the specific fuel consumption compared to a system using preheated air. This design decision, in essence, makes the system a cogeneration plant (and a waste incinerator) and reflects the results of the market analysis, which suggests that the benefits of avoiding disposal and heating fuel costs will far outweigh the benefits of on-site electrical generation.

Future Development

The BioStirling system will be introduced to the market via selective demonstration programs involving commercial organizations or parties affiliated with commercial entities, that need the system and that are known high-exposure participants in the biomass market.

- A joint venture with a major industrial partner is now in the process of being formed.
- The bulk of marketing (sales-service-distribution) will be the responsibility of the industrial partner.
- STM shall remain the technology provider to the joint venture and assume some manufacturing functions for the production of Stirling-specific components.
- Future development and deployment funding is envisioned from a variety of sources, depending on the market and dominant pacing items involved
- Internal R&D funds from the joint venture
    - Agencies with dedicated biomass programs resolving environmental concerns connected to biomass
    - Multinational aid and funding organizations
    - Revenues from commercial sales.